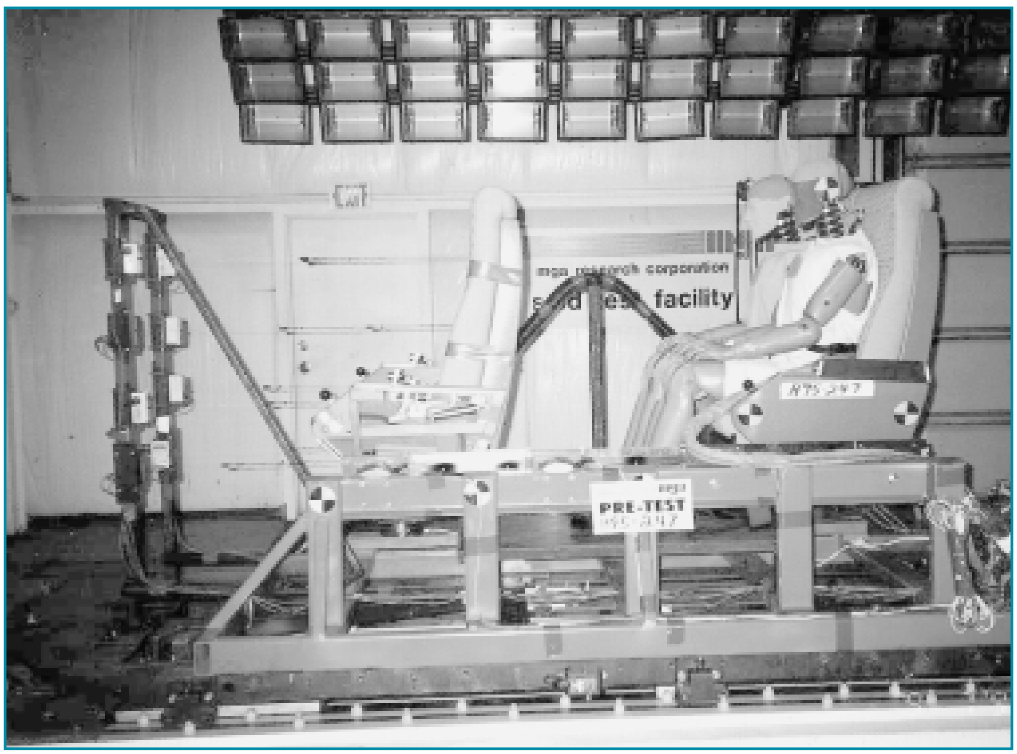
TRAIN OCCUPANT SAFETY



EMERGENCY PREPAREDNESS

SUMMARY

The Federal Railroad Administration, in partnership with Amtrak and commuter passenger train systems, is stressing the need for advance planning in order to respond effectively to emergencies. This planning addresses emergency response procedures, training of system operating and other emergency response organization personnel, and the provision and use of emergency equipment.

RESEARCH STATUS

The Volpe Center reviewed the emergency preparedness practices in use by Amtrak and the various commuter rail operations nationwide as well as relevant information on policies and procedures from the transit industry. This information, as well as additional emergency preparedness procedures developed by Volpe Center staff, served as the basis for the report, Recommended Emergency Preparedness Guidelines for Passenger Trains, published by the FRA in 1993. The guidelines are intended to assist passenger train system operators to assess, develop, document, maintain, and improve their emergency response capabilities, and to coordinate these efforts with emergency response organizations in a manner which best protects the traveling public and system passenger trains and facilities. The recommendations provide a useful framework for these organizations to evaluate and, if necessary, modify or supplement their emergency preparedness plans and procedures, and related training, and passenger train and facility equipment design and operations.

The development of the recommended guidelines document was supported by representatives from Amtrak and several commuter rail systems. These representatives provided important inputs regarding their emergency response programs, and the practicality of the recommendations. Rail system management and labor representatives also provided

Emergency Exit Window

input into the Passenger Train Emergency Preparedness Final Rule.

The recommended guidelines report serves as a baseline resource document in the development of the FRA's passenger train emergency preparedness component of the Passenger Equipment Safety Standards, which the FRA was required to develop as a result of the 1994 Swift Rail Act.

FUTURE RESEARCH

Now that a framework for emergency planning has been created, the FRA Office of Research and Development has requested that the Volpe Center conduct a study that concentrates on specific, safety-sensitive details related to emergency evacuation. These topics include: emergency exit size, type and location; emergency lighting levels; signage, and exterior rescue access.

The passenger train evacuation study is being coordinated with work performed by the American Public Transit Association (APTA)/Passenger Rail Equipment Safety Standards (PRESS) Committee.

The FRA Office of Research and Development staff continues to work with the various operating entities responsible for passenger rail services through industry workshops, emergency drills, and training needs development.

FIRE SAFETY

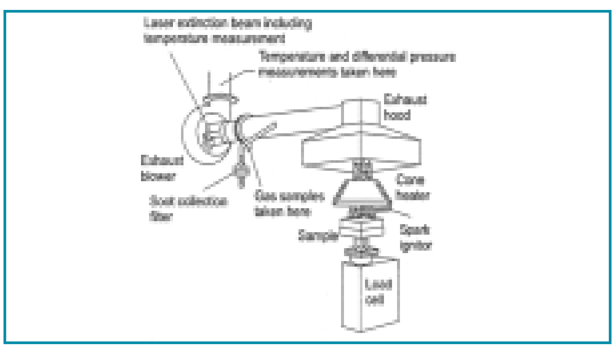
In 1989, the Federal Railroad Administration reissued fire safety guidelines (first published in 1984) which address the flammability and smoke characteristics of materials used in intercity and commuter passenger cars. The European fire safety approach uses test methods similar to the FRA guidelines, but certain differences of potential concern have been identified as a result of preliminary safety reviews of the German maglev and French TGV technologies by the FRA.

In 1993, the National Institute of Standards and Technology (NIST) completed a comprehensive evaluation of the U.S. and European approaches to passenger train fire safety for the FRA. In addition to test methods for material, the effects of vehicle design, detection and suppression systems, and emergency egress were reviewed. A major conclusion of the NIST study was that the use of fire hazard and fire risk assessment supported by measurement methods based on heat release rate (HRR) could provide a means to better predict real world fire behavior.

RESEARCH STATUS

A demonstration program is now underway to validate the use of HRR test methods as an alternative to the currently cited FRA test method. This program consists of the following phases:

Phase I: Evaluate selected materials that have been tested according to older test methods, using HRR test method technology. The evaluation included the comparison of Cone Calorimeter HRR test data and test data from current FRA cited tests methods and performance criteria. Necessary quantitative data was used as an input for a fire hazard analysis, using a computer model specific to passenger train vehicles. Phase I work has been completed and a report published, entitled *Fire Safety of Passenger Trains - Phase: Material Evaluation* in the Cone Calorimeter, Interim Report, DOT-VNTSC-FRA-98-2.



Cone Calorimeter Test Apparatus

Phase II: Evaluate the applicability of a hazard analysis using a computer fire model of the overall fire safety of passenger trains. The evaluation included conducting furniture calorimeter tests to provide additional HRR data. Material controls and vehicle design, detection and suppression systems, and emergency egress and their interaction were analyzed to assess the relative impact on fire safety for a range of design parameters. The Phase II tasks have been completed and a report is in final preparation.

Phase III: Perform selected real-scale proof testing of a complete full-size rail car to verify the small-scale HRR criteria and hazard analysis studies in actual end use configuration.

KEY FINDINGS

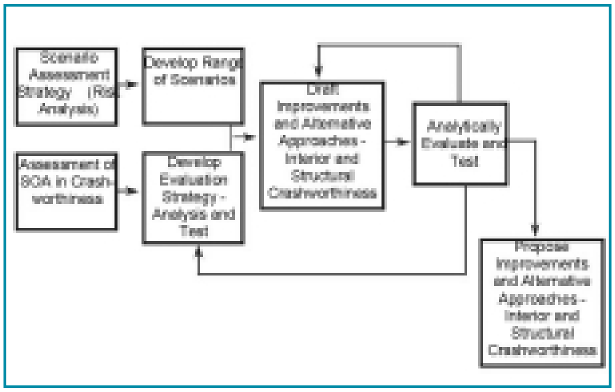
The results of the Phase I study demonstrated strong correlation between the flammability smoke emission data generated from the existing FRA fire safety guideline-cited test and heat release rate data generated from the Cone Calorimeter.

FUTURE RESEARCH

Finally, since fire safety has been identified as an important element of overall system safety for the new passenger train technologies, work will continue to provide additional general fire safety support to the Office of Safety. The support will include technical consultation with Amtrak regarding the fire performance of material proposed for new high-speed train sets, as well as new conventional train equipment. Worldwide developments concerning methods for preparing for and dealing with fires in railroad tunnels also will be monitored.

COLLISION MECHANICS, CRASHWORTHINESS, AND OCCUPANT PROTECTION

In order to provide a framework for this effort, collision safety research has been grouped into two categories: **collision scenario assessment, and interior crashworthiness**. Collision scenario assessment is the analytic evaluation of the intended application of passenger equipment in order to identify the potential collisions in which the equipment may become involved and the evaluation of accident data to determine the causes of injury and fatality. Interior crashworthiness is comprised of those features of the train crew and passenger volumes which act to limit the forces and decelerations imparted to the occupants to survivable levels during a collision.



Collision Safety Research Project

Collision Scenario Assessment

Vehicle crashworthiness requirements are defined by the collision scenarios in which the vehicle is likely to become involved. In turn, the likelihood of these scenarios is dependent upon the system in which the train is operated and the features of the system and measures taken to avoid these scenarios.

The primary objectives for structural crashworthiness are to maintain the integrity of the occupant compartment and to control the deceleration of the occupant compartment. The occupant compartment must be able to preserve at least a minimum occupant survival volume, be able to minimize local compartment penetration, and be able to ensure occupant containment within the compartment space. In order to minimize injury, the accelerations and forces imparted to the occupants must be kept sufficiently low during a collision. In order to meet this objective, the occupant compartment must be decelerated at a sufficiently low rate. In order for this deceleration to be sufficiently low, the vehicle structure must be able to absorb an appropriate amount of energy.

Interior Crashworthiness

In order to minimize injury, the accelerations and forces imparted to the occupants must be kept sufficiently low during a collision. These decelerations and forces depend upon the interior arrangement as well as the deceleration of the occupant volume (crash pulses). To minimize the effects of secondary impacts, the interior of the compartment must be appropriately contoured and padded. To eliminate as many secondary impacts as possible, luggage and interior fixtures must all be adequately restrained. How well a particular interior arrangement minimizes injury can be evaluated for a range of potential occupant volume crash pulses.

RESEARCH STATUS

Recent crashworthiness research includes the following:

- Assessment of the State-of-the-Art
- Accident Avoidance
- Accident Survivability
- Analysis of High-Speed Crashworthiness Options
- Locomotive Crashworthiness Research
- Rail Vehicle Crashworthiness Symposium
- Dynamic Sled Testing of Passenger Seats

A description of each of these research areas follows.

Assessment of the State-of-the-Art - The Volpe Center has been supporting the FRA by creating and analyzing various collision scenarios and developing safety guidelines and specifications for high-speed ground transportation (HSGT). Existing U.S. and foreign rules and regulations, standards, and practices were reviewed as a starting point for this project. The FRA has put forth a comprehensive effort to develop the technical information necessary for regulating the safety of HSGT.

In recent years the interest in HSGT has increased. All the systems proposed for operations at speeds greater than current practice employ technologies that are different from those presently in use. The greater potential consequences of an accident at high speeds require the assurance that HSGT systems are safe for use by the traveling public and operating personnel.

Accident Avoidance - Collision safety comprises the measures taken to avoid collisions and ensure passenger and crew protection in the event of an accident. The results of studies conducted provide a basis for evaluating the collision safety provided by a given HSGT system.

Collision avoidance is accomplished in three ways. The first method is to determine the integrity of the route. The idea is to ensure that the track or guideway is clear of other trains, vehicles or obstructions. Modern software driven in microprocessors are used to control this interlocking system. The second part of collision avoidance relates to the communication of the authorized movements to an operator or to the control system which can be an automatic train operating system. The final control element is speed. This function is carried out by the automatic train protection (ATP) system. The control of the speed and the enforcement, that is, the ability of the system to override the operator, are included in the functions supplied by the safe-speed enforcement part of the control system. Continuous ATP systems maintain a constant guideway-to-train communication. Coded track circuit systems of this type are in use today in other countries.

Accident Survivability - This involves a number of issues including the structure of the vehicle - its design parameters, the interior fittings, and window glazing. The structure should be designed to optimize the absorption of collision forces in areas that are not occupied by passengers. The occupants need to be protected during the second collision; that is, the one where they are in motion and the vehicle is not.

Analysis of High-Speed Crashworthiness Options - The Volpe Center has been providing support to the FRA in developing the technical basis for crashworthiness specifications for rail passenger equipment. The work described here is a part of the High-Speed Ground Transportation Safety Program of the FRA. The results of these studies have been used in discussions with Amtrak on safety considerations related to the purchase of Northeast Corridor high-speed trainsets.

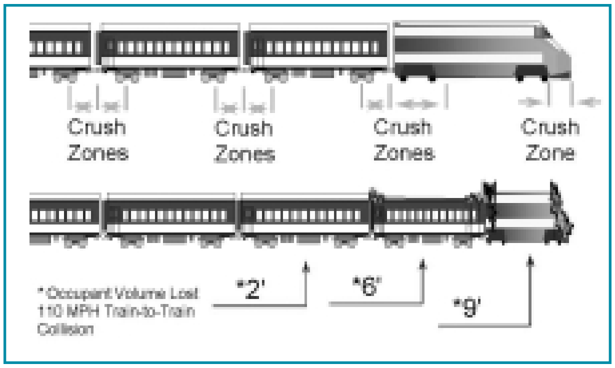
The FRA evaluated different strategies for the design of rail vehicle structure to protect the occupants. There are two types of collisions with which to deal. One is the primary collision between the train and the impacted object. The second is between the occupants and the interior including loose objects inside the train such as baggage.

Causes of fatalities include crushing of the occupant in the primary collision and excessive deceleration of the head or chest of the occupant and axial neck loads during the secondary collisions inside the train.

Conventional design practice results in cars of the uniform longitudinal strength. The crash energy management system requires varying strength through the train. High strength is required in the occupied areas and lower strength in the unoccupied areas.

The interior configurations were studied considering data on head injuries, chest deceleration times, and axial neck load. These issues are all part of the secondary impact problem.

The use of compartments can be as effective as a lap belt in minimizing the probability of a fatality. Compartmentalization is a method of occupant pro-



Constrained Crash Energy Management Design

tection that requires seats or restraining barriers to be positioned in a manner that provides a compact, cushioned protection zone surrounding each passenger.

Three different interior configurations were evaluated for effectiveness involving lap belts and lap belts with shoulder restraints. The interior configuration influences which interior surface the occupant strikes and which part of the occupant strikes the interior. Vehicle deceleration influences how hard the occupant strikes the interior surface.

Additional data on secondary impacts are needed. The most effective way to reduce injury in train collisions may be to gather information from the victims of actual accidents. Detailed structural analyses and testing are needed to develop structures which implement the crush zones and to evaluate the potential for increased occupant volume strength.

KEY FINDING

One principal conclusion is that a sufficiently compartmentalized interior protects the occupants against fatality during train collisions at least as well as required in the automotive and aircraft industries. Seat belts provide some level of increased protection from fatality owing to secondary collisions; however, most fatalities during train collisions are predicted to be from loss of occupant volume.

Locomotive Crashworthiness Research - In September 1992, Congress passed Public Law 102-365, the Railroad Safety Enforcement and Review Act (RSERA), requiring, in part, that the Secretary of Transportation conduct research and analysis to consider the costs and benefits of several types of crashworthiness improvement features. These features include braced collision posts, crash refuges, rollover protection devices, uniform sill heights, deflection plates, anticlimbers, shatterproof windows, and equipment to deter post-collision entry of flammable liquids.

Locomotive-locomotive Collision, 30-mph Closing Speed

As part of the response to RESRA, computer models were developed and related engineering calculations were made to analyze the crashworthiness of the cab area in existing road freight locomotives. In addition, the models provided quantitative estimates of the costs and benefits of the crashworthiness improvement features.

The study team performed its evaluation using the Association of American Railroads (AAR) industry standard, S-580. This standard applies to new road-type locomotives built after August 1, 1990, and requires three of the features listed above: collision posts, anticlimbers, and the short hood feature that

TOTAL OCCUPANT VOLUME LENGTH LOST (feet)

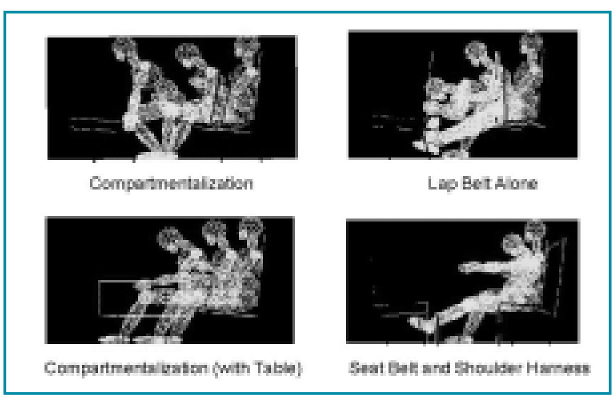
COLLISION CLOSING SPEED (mph)	CONVENTIONAL DESIGN	CRASH ENERGY MANAGEMENT DESIGN
35	0	0
70	9	2
110	22	17
140	69	57

is considered, in part, as equipment to deter post-collision entry of flammable liquids.

KEY FINDING

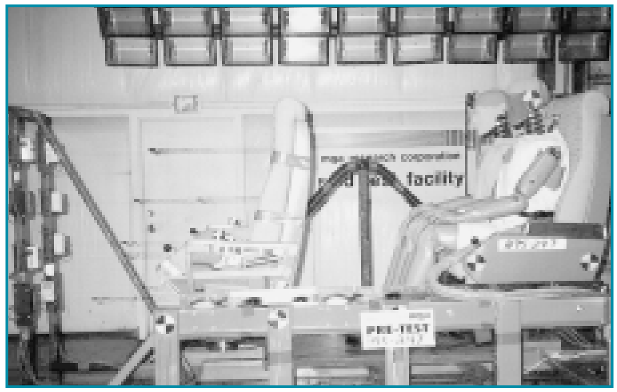
The study found it feasible to provide practical improvement to freight locomotive crashworthiness by making modifications to some of the features listed in the Public Law. In particular, an increase in the strength of the collision posts over that specified in S-580 appeared to provide the clearest benefit. Implementation of a deliberate crash refuge and use of glazing with higher penetration resistance also appear to be feasible for practically improving crashworthiness. An interlocking anticlimber with closely matching underframe neutral axes (rather than sill heights) will provide increased protection against cab crush, especially when used with the stronger collision post concept.

Rail Vehicle Crashworthiness Symposium - The Rail Vehicle Crashworthiness Symposium, sponsored by the FRA, Office of Research and Development, was held at the Volpe Center on June 24-26, 1996, and was attended by 95 members of the international community of rail transportation experts. The objective of the symposium was to present results of current research on rail vehicle collision safety and passenger rail equipment crashworthiness design and to provide a forum for exchange of technical information between research organizations, passenger railroad operators, equipment manufacturers, and constituent organizations concerned with rail passenger car collision safety.



Occupant Protection Strategies

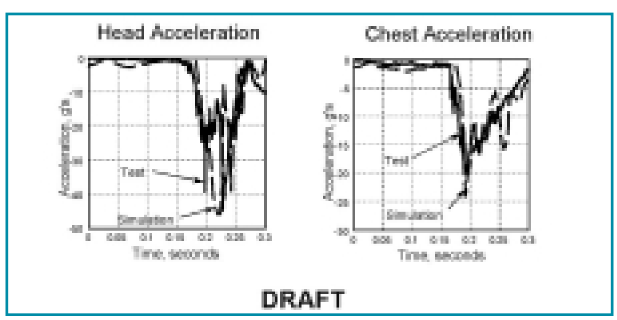
Dynamic Sled Testing of Passenger Seats - The Volpe National Transportation Systems Center has been supporting the FRA in analyzing the crash responses of high-speed and conventional-speed passenger trains. The analyses have been performed using computational tools developed for the automotive industry. The experimental data obtained during this test effort provide a better understanding of the occupant response and seat performance during the secondary impact in the event of a train collision. The data also validate the simulation results over the range of variable seat parameters analyzed with the present computer model.



Sled Testing of Passenger Seats

During 1996, the first in a series of tests was performed by MGA Research Corporation at its automotive test and proving grounds in Burlington, Wisconsin, and at its test facility in Detroit, Michigan. The test effort was conducted in cooperation with Amtrak, which provided the seats, and the National Highway Traffic Safety Administration (NHTSA), which provided the test dummies.

Tests were conducted using traditional passenger seats to evaluate their performance under static and dynamic loading conditions. Quasi-static tests were



Test Results Vs. Simulation

conducted to establish the load-deflection characteristics of the seats. Dynamic tests of selected collision conditions were conducted with instrumented dummies to evaluate the collision performance of the seats and to verify the analytic simulation tools.

Injury criteria measured and calculated included head injury criteria, chest deceleration time, axial compressive neck load, and femur load. The injury criteria for the dynamic tests were within the acceptable human tolerance levels as specified in NHTSA and Federal Aviation Administration standards.

The quasi-static testing indicated the seats were sufficiently strong to withstand the occupant loads predicted from the computer simulation. However, under dynamic loading conditions, the seat attachments were prone to failure, particularly at the wall mount.

These test failures possibly were due to the inertial effects of the seat which were not present during the static tests.

The dummy's head and chest deceleration time histories and injury criteria from the dynamic tests were compared to the results of simulations corresponding to each of the dynamic tests. The comparisons demonstrate reasonable agreement between the analytic predictions and the dynamic test results, given the variability of the effective stiffness of the seats under different loading conditions.

RESEARCH STATUS

Current projects include the following:

Cab Car Crashworthiness Study - The objective of this study is to determine an effective means of protecting the cab car operator and occupants during a collision. Cab car structural crashworthiness strategies employed worldwide, particularly those employing crush-zones, will be reviewed.

Crash-Energy Management Design Study - The objective of the Crash Energy Management Design Study is to demonstrate the feasibility of designing and implementing an energy management system into an intercity train. The energy management system shall substantially improve collision safety for train passengers.

Over-Ride and Lateral Buckling Study - The objective of this task is to determine strategies for preventing car-to-car over-ride and trainset lateral buckling during train collisions.

In-Line Collision Test Planning - Develop plans for tests to measure data for comparison with analytic models of car crushing and of train collision mechanics and tests to measure the secondary collision environment during in-line train collisions. The tests being planned are arranged to measure the behavior of main structure elements of passenger cars under failure conditions, and to measure the crushing of the car and gross car motions (i.e., over-ride and/or train buckling) during a collision.

Lap and Shoulder Belt Feasibility Study - The principal objectives of this study are to develop the design requirements for an intercity and commuter passenger coach seat which incorporates lap and shoulder belts, to develop an engineering model (proof-of-concept) design for a seat which meets these requirements, to estimate the associated costs, and to estimate the potential reduction in effectiveness of seat and lap belts owing to misapplication.

FUTURE RESEARCH

Research planned for the next several years includes, but is not limited to, the following areas:

- Evaluate the influence of occupant size on the likelihood of life-threatening injury.
- Determine the performance of current passenger equipment when struck in the side by a highway vehicle.
- Determine the performance of current passenger equipment during derailment and rollover.
- Evaluate single-car oblique collision dynamic test using existing and new data.
- Conduct passenger secondary collision parametric study.
- Conduct cab car operator secondary collision protection study.
- Conduct single passenger car oblique collision dynamic test to measure the trajectory of the cars during the collision, to measure the secondary collision environment, and to measure the crushing of the complete car structure for new cab car design.

- Conduct first single passenger car in-line collision dynamic test to measure the trajectory of the cars during the collision, to measure the secondary collision environment, and to measure the crushing of the complete car structure.